E-ISSN No: 2454-4639

Trend of Particulate Matter in the Ambient Air of a Small City in India

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ABSTRACT

Air pollution has serious and widespread effects on health, economy and climate. Most of the studies on air pollution were focused on megacities. As a pioneering work, the study involved elaborate air monitoring and sampling in Rewa, a small urban center in the central India to assess and analyze the atmospheric Particulate Matter (PM) and toxic gasses as the impact of urbanization and economic growth spurred by economic liberalization in the country. The study assessed the trends of pollution in a small city with seasonal and spatial variations for source identification and generating reliable database. Automobile exhausts were identified as a major source of pollution. Though the gaseous pollutants were within the limit of prescribed standards, the statistics of PM were remarkably far greater than the national and international standards. Alarming level of PM in the city is noticeable, especially given its established carcinogenicity to humans. This study confirms looming pollution threats to the small city at the same time bridges the data gap and improves information availability based on trusted quality monitoring and sampling. It may provide significant insights into the status of air quality of small cities of other developing countries across the glove having common dynamics of the economy, demography and infrastructural factors.

Key Words: Air quality, RPM, SPM, pollution, PM.

INTRODUCTION

The air is so vital for life that its pollution becomes a critical issue. The air quality is a major concern the world over, particularly in developing countries. Particulate Matter (PM) varying from coarse to fine and ultra-fine particulates are the characteristic features of ambient air of most of the urban centers of the world. The impact of air pollution is huge in terms of health, crop productivity and environmental costs. 23 percent of the global disease burden is attributable to the environmental pollution, and some 1.3 million premature deaths yearly are caused due to outdoor air pollution alone (WHO, 2013)[1]. Recently, air pollution as a whole has been classified as a carcinogenic to humans by the International Agency for Research on Cancer (IARC), an agency of WHO (2013)[1]. PM, the major component of outdoor air pollution has been evaluated separately and also classified as carcinogenic to humans. According to WHO's *World Cancer Report 2014*, the globe is facing a ‘tidal wave’ of cancer. It predicts the number of cancer cases will reach 24 million a year by 2035 and the developing world will bear the brunt of the extra cases[1].

PM consists of various small and large particles emanating from both natural and anthropogenic sources. PM in air is continuously increasing. The nature and dynamics of air pollution are changing with changes in causal agents like population size, vehicular traffic and diverse anthropogenic activities coupled with changes in climatic conditions. It has emerged as a new challenge before the whole world and there is a significant need of regular updates on the subject with a greater spatial and temporal resolution for better understanding of the dynamics of atmospheric aerosols in the Indian context[2]. Increased PM in terms of Respirable Particulate Matters (RsPM) and Suspended Particulate Matters (SPM) concentrations was reported in Delhi [3,4] and in many parts of India and the world in various studies[5-11]. This atmospheric condition is not only confined to metro cities or mega highways. With fast-paced urbanization, this trend is being observed in small cities of India as well.

Since most of the pollution studies in India focused on megacities, as smaller cities were generally taken as clean. This study aimed at assessing the ambient air quality of Rewa city, a small urban center to assess and analyze the unique status of atmospheric dust load (SPM and RsPM) and key toxic gasses as the impact of urbanization and economic growth of a

E-ISSN No: 2454-4639

decade and a half during post-economic liberalization in India.

The goals of this study were to: (1) assess the ambient air quality and explore the changing trend of air pollution of a small city; (2) check the seasonal and spatial variations of pollutants for source identification and their contribution; (3) to generate reference database and to draw attention to the status of deteriorated air quality of a small city. Thus, the study invites attention to the status of air pollution in a small city of India. It addresses the data gap and improves information availability based on trusted and accurate source of quality monitoring and sampling.

MATERIALS AND METHODS

The study was conducted in 2006-07 in Rewa city, a typical small urban center in the central India in Madhya Pradesh. It is located at 24^0 -21 latitude North and 81^0-21' longitude East and at 316 meters above mean sea level (MSL) on Rewa-Panna plateau flanked by Vindhyan mountain ranges in the north and Kaimore ranges in the south. The city has a humid subtropical climate with cold misty winters, hot summer (when the highs regularly exceed 40^0 C) and humid monsoon season (annual rainfall of about 41 inches). The city has a population of 183 thousand (2011) and emerged as an educational and manufacturing hub. It has a well recognized university and several colleges. Well known for white tigers, it is an entry point to many tourist places and some major state and national highways passages through the city. There are two mega cement plants and some SMEs including some stone crusher units on the outskirts.

Air Quality Analysis: Air quality studies were conducted at ten selected sites, including highways, busy crossings and major roadsides of the city. SPM, RsPM and key gaseous pollutants such as SO_2 and NO_2 were monitored by Respirable Dust Sampler (Envirotech Model APM 460 BL-411) for 8 hours in a day as per the standards of the Central Pollution Control Board (India). RsPM was collected on glass fabric (GFA-3) filter papers and SPM was collected in the dust cup. The gaseous pollutants SO_2 and NO_2 were collected in sodium tetra-chloromercurate and sodium hydroxide arsenate solutions respectively. The samples were analyzed as per methods described in the manual of Respirable Dust Sampler (RDS) and National Environmental Engineering Research Institute (NEERI).

Quantification of RsPM: The RsPM samples were collected on Glass Fabric (GFa) filter paper which were kept in a hot air oven at 105^0C for 2 hours and then cooled to weigh. The similar procedure was done before sampling to take pre-weight of GFa filter paper.

Calculation: **RsPM (μg/m^3) = $(I\times10^6) / K$,**

Where, I=Dust accumulated on filter paper, K=Total volume of air passed through filter paper (m^3), $I=B_2-B_1$, B_2=Weight of filter paper after sampling (gm), B_1=Weight of filter paper before sampling (gm), $K=G\times T$, G (Average flow rate) = (A_1+A_2) / 2, A_1=Initial flow rate indicated by manometer, A_2=Final flow rate indicated by manometer, T=Time of sampling (minutes).

***Quantification of SPM*:** The SPM was collected in the dust cup and calculated as follows:
Calculation: **SPM (μg/m^3) = $(J\times10^6) / K$**

Where, J=Dust accumulated on dust cup, K=Total volume of air passed through cyclone (m^3), $J=D_2 - D_1$, D_2=Weight of dust cup after sampling (gm), D_1=Weight of dust cup before sampling (gm), $K=G\times T$, G (Average flow rate)=(A_1+A_2) / 2, A_1=Initial flow rate indicated by manometer, A_2=Final flow rate indicated by manometer, T=Time of sampling (in minutes).

Quantitative NO_2 analysis: Nitrogen oxide was collected by bubbling polluted air through a sodium hydroxide-sodium arsenite solution. Any water loss through evaporation during sampling was replaced by adding distilled water up to the calibration mark on the absorption tube. 1 ml hydrogen peroxide solution, 10 ml sulphanilamide solution and 1.4 ml NEDA solution were added with thoroughly mixing after the addition of each reagent. Absorbance was measured using spectrophotometer at 540 NM after 10 minutes of color development. The standard nitrite solution was prepared from sodium nitrite so

The Indian Journal of Basic and Applied Research
Volume 1 |Issue 4| Feb 2016
Online & print@ www.ijbar.co.in
E-ISSN No: 2454-4639

that a solution containing 1,000 μg NO_2/ml was obtained.

Calculation: Volume of sampled air was calculated as: $V = \{(E_1+E_2) / 2\} \times T$

Where, V=Volume of sampled air, E_1=Initial Rota meter reading (LPM), E_2=Final Rota meter reading (LPM), T=Time of sampling (minutes).

Mass of Nitrogen Oxides (μg/m³) = {(μgNO₂ ml) × 100} / V

$$\text{Mass of Nitrogen Oxides } (\mu g/m^3) = \{(\mu g NO_2 \text{ ml}) \times 100\} / V$$

Where, V=Volume of air sampled (Liter), 10^3=Conversion liter to cubic meter.

Quantitative analysis of SO_2: Ambient *S*ulfur dioxide was trapped in a solution of sodium tetra chloromercurate (absorbing reagent). In this solution 1 ml Sulfuric acid, 2 ml of 0.2% formaldehyde (HCHO) and 2 ml para-rosaniline hydrochloride were added and waited for 30 to 60 minutes. The absorbance was measured using spectrophotometer at 560nm and quantification was done by comparing it with a standard curve. The standard curve was drawn with the help of a standard solution of SO_2. For this purpose, the standard solution of SO_2 was prepared by dissolving 0.3 gm sodium metabisulfite or 0.4 gm sodium sulphite in 500 ml of boiled and cooled distilled water. 2 ml of this standard solution was put into a 100 ml volumetric flask and brought to 100 ml with absorbing reagent.

Calculation: Volume of Sampled air was calculated as: $V = \{(E_1+E_2) / 2\} \times T$

Where, V=Volume of air sampled, E_1=Initial Rota meter reading (LPM), E_2=Final Rota meter reading (LPM), T=Time of sampling (minutes).

$$\textbf{Mass of } SO_2\ (\mu g/m^3) = \{(\mu g SO_2 \text{ ml}) \times 100\} / V$$

Where, V=Volume of air sampled (lit.), 10^3=Conversion Liter to cubic meter.

Statistical Analysis: Statistical Analysis was done by the "GraphPad In Stat 3" software, Student's t-test and Coefficient of correlation were applied for interpretation.

RESULTS AND DISCUSSIONS

The study assessed the trends of pollution with seasonal and spatial variations for source identification and generating reliable database.

Annual Concentration: Average annual concentrations and seasonal variations of PM and gaseous pollutants of the ambient air of the city may be seen in Table I, II and III. The average annual concentrations of key pollutants were recorded as 520.54 μg/m³ for RsPM, 2829.89 μg/m³ for SPM, 8.40 μg/m³ for SO_2 and 76.22 μg/m³ for NO_2 (Figure I). This clearly establishes the domination of PM in the ambient air of the city.

Figure I Annual average of air pollutants in ambient air of Rewa city

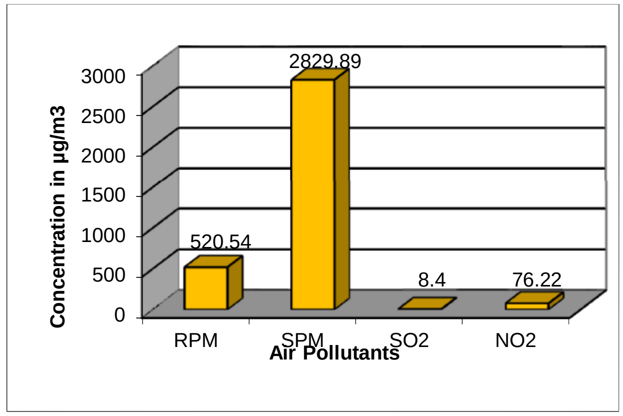

Table I Average aerosol & gaseous concentrations in the ambient air at various sites of Rewa City during summer season (μg/m³).

Sampling site	RsPM	Non-RsPM	SPM	SO_2	NO_2
Stadium Chowk	153 ±3	393±2	546±5	1±1	30±2
Sirmaur Chowk	230 ±4	695±4	925±8	2±1	28±3
UTD	74 ±3	442±4	516±7	1±1	7±2
Saman Chowk	405 ±5	1354±3	1758±7	1±1	29±3
PTS Chowk	515 ±5	4432±4	4947±8	7±3	39±4
Dhobia Tanki	535 ±5	2914±5	3448±1	1.5±1	31±3
Civil Lines	146 ±5	117±4	262±9	1±1	18±2
Jaistambh Chowk	416 ±5	1392±5	1808±9	5±2	43±2
Nagar Nigam	365 ±4	1479±4	1844±8	1±1	13±2
Prakash Chowk	451 ±3	1478 ±2	1929±5	2±1	19±2

The values of PM in terms of RsPM and SPM were far greater than the standards of the CPCB, India and the WHO for both the residential and commercial areas. The values of gaseous pollutants were within the prescribed limit or slightly higher.

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A comparative air quality data of the city along with national and international standards may be seen in Table IV. The average annual concentrations of RsPM and SPM were respectively 8.7 times and 20.2 times higher than the standard limit of residential areas prescribed by the CPCB, India (Table V).

Table II Average aerosol and gaseous concentrations in the ambient air at various sites of Rewa City during rainy season (µg/m^3).

Sampling site	RsPM	Non-RsPM	SPM	SO_2	NO_2
Stadium Chowk	230 ±4	471±2	701 ±6	1±0.4	106±3
Sirmaur Chowk	301 ±2	766±4	1066 ±6	10±3	121±2
UTD	139 ±3	509±2	648±5	1±0.4	25±3
Saman Chowk	475 ±3	1423±3	1898±6	2±1	118±4
PTS Chowk	589 ±3	4506±3	5096±7	28±4	139±3
Dhobia Tanki	611±3	2992±3	3602±5	8±3	124±5
Civil Lines	212±3	182±3	393±7	6±1	60±3
Jaistambh Chowk	496 ±3	1471±2	1968±6	15±2	149±3
Nagar Nigam	445 ±3	159±3	2005±6	6±1	67±2
Prakash Chowk	522±3	1548±3	2069±1	5±1	58±0.5

Remarkably, average annual concentration of RsPM in the city was observed to be higher than those of Delhi (217.33 µg/m^3), Kolkata (184.67 µg/m^3), Mumbai (118.0 µg/m^3) and Chennai (67.17 µg/m^3) as per CPCB records (2005). This figure is higher than recorded in Coimbatore [12] and Delhi [13]. While study on RsPM in Kathmandu says that its concentration in urban, sub-urban and urban-background were respectively 4.0, 2.08 and 1.40 times the standard[2]. It indicates higher values of RsPM in urban areas[14]. Similarly, higher concentrations of RsPM were observed in different urban centers.[5-10]

The higher RsPM and SPM levels in the ambient air of the city may possibly be attributed to the steep rise in the number of the vehicles, the density and average speed of the traffic and the condition of road infrastructure besides meteorological factors, as there were no major air polluting industries located in the study area or its close vicinity.

Table III Average aerosol and gaseous concentrations in the ambient air at various sites of Rewa City during winter season (µg/m^3).

Sampling site	RsPM	Non-RsPM	SPM	SO_2	NO_2
Stadium Chowk	1195±2	2092±2	3287±4	7±2	125±4
Sirmaur Chowk	503±3	2086±3	2588±6	18±2	15±4
UTD	1071±3	350±3	1421±5	6±2	40±2
Saman Chowk	2411±2	8438±2	10848±1	11±2	144±3
PTS Chowk	264±3	11338±2	11601±1	34±2	163±3
Dhobia Tanki	637±2	2368±2	3005±4	14±1	146±2
Civil Lines	109±4	347±2	456±6	10±2	81±2
Jaistambh Chowk	1383±3	7695±3	9079±6	23±2	175±3
Nagar Nigam	606±4	2279±2	2885±6	15±2	89±4
Prakash Chowk	130±2	2166±2	2296±1	13±2	84±3

Table IV Comparative data on air quality standards of annual mean pollutant concentrations in the ambient air of WHO, CPCB and of Rewa City (µg/m^3).

Site/Standard	SPM (µg/m^3)	RsPM (µg/m^3)	SO_2 (µg/m^3)	NO_2 (µg/m^3)
REWA CITY	2829.87	520.54	8.40	76.22
CPCB	140	60	80	80
WHO	–	20	20 (24 hrs mean)	40

Nearest industrial units of cement plants were located some 20 km away. The numbers of vehicles, traffic conditions and climatic factors of the urban areas may affect air pollution. [14, 15] A remarkable number of vehicles plying in the city were possibly not following the emission norms strictly either. Apart from vehicular emissions, burning garbage and backyard water may be other sources. According

 E-ISSN No: 2454-4639
International Innovative Journal Impact Factor (IIJIF)

to an estimate of IGIDR (2000) burning of a ton of garbage produces 0.098 tons of SPM[16].

Table V Seasonal average concentrations of pollutants in the ambient air of Rewa city (µg/m^3).

Seasons	RsPM	Non-RsPM	SPM	SO_2	NO_2
Winter	831±708	3916±380	4747±411	15±8	106±53
Summer	329±165	1470±131	1798±145	2±2	26±11
Rainy	402±17	1403±139	1945±146	8±8	97±41

Seasonal variation: Air pollution statistics of the city showed significant seasonal variation (Table V and VI). All the parameters showed very significant changes as RsPM (P=0.0202), SPM (P=0.0319), SO_2 (P=0.0012) and NO_2 (P=0.0001). Comparatively higher concentrations of pollutants have been recorded during the winter months, followed by the monsoon and the summer months. This seasonal variation under present study may be attributed to variation in meteorological factors like wind velocity, temperature, relative humidity as well as periodic rainfall [17]. The range of variation for RsPM was 329 to 831 µg/m^3 and for SPM 1798 to 4747 µg/m^3 from summer to winter seasons. Similarly, SO_2 ranged from 2 to 15 µg/m^3 and NO_2 ranged from 26 to 106 µg/m^3 showing an increasing trend through summer to winter season for all the sites. This suggests the influence of meteorological factors on the transportation and the dispersion mechanism of air pollutants.

Winter months are critical period for accumulation of certain pollutants because of its cool and calm conditions. The steady wind flow and low temperature facilitate higher density of pollutants near the ground level. The climatic conditions during winter months prevent dispersion and transportation of pollutants to the upper atmosphere[18]. The calm weather conditions with low wind speed favor collection of PM_{10} and consequent increase in the pollution of the atmosphere[19]. A negative correlation was observed between wind speed and concentration of RsPM[12], indicating that higher wind speed has a higher dispersion effect on fine PM, especially PM_{10}. Therefore, calm weather, low wind speed and temperature were probably the reasons for higher concentrations of pollutants in the ambient air of the city during the winter months.

Table VI One-Way ANOVA showing the significant seasonal changes

Air Quality Parameters	F-value	P-value at DF 2 &27 and 0.05%
RsPM	4.528	0.0202,Significant
Non RsPM	3.399	0.0482,Significant
SPM	3.927	0.0319,Significant
SO_2	8.697	0.0012,Very significant
NO_2	12.547	0.0001,extreamly significant

Summer months in the city are characterized by strong wind speed, high temperature, low humidity-almost no rainfall to occasional showers. The low concentrations of air pollutants during the summer months of the present investigations may probably be attributed to these meteorological factors. The strong wind speed during these months might have carried away the pollutants to long distance and prevented them from settling down to the ground [17]. Lower concentration of air pollutants during summer months have also been reported [20].

During the monsoon months, meteorological factors seem to play an important role in deciding concentrations of pollutants in the air. Higher levels of RsPM and SPM were observed during these months in comparison to the summer months. Although raindrops are known to prompt washing out by natural scrubbing process during monsoon, however, in this case the city was undergoing a severe drought for the last three years. The scanty rainfall and low wind speed as well as high relative humidity may have prevented the dispersion and transportation of pollutants, especially the PM to the upper atmosphere. In all likelihood this was the reason for higher concentration of RsPM and SPM in the city during monsoon months than summer months.

 E-ISSN No: 2454-4639

Inter-site variations: Significant inter-site variations of PM and gaseous pollutants have been observed (Table VII) which explain the other dynamics of pollution. The comparative difference in vehicular density and differential degree of commercial activities associated to the sampling sites might be the reason for inter-site variations in air pollution.

Table VII Two way ANOVA showing inter-site and intra-seasonal (P_c-value) with inter-site seasonal changes (P_R -value)

DF 2 & 18	Pc-value	P_R-value
RsPM	0.0338 *	0.3993
Non-RsPM	0.0876 *	0.0317 *
SPM	0.3726	0.4618
SO_2	0.0001 ***	0.0001 ***
NO_2	0.0001 ***	0.0055 **

*Significant, **moderately significant, *** extremely significant

It is obvious from the findings that due to rapid growth in vehicular traffic and the infrastructural constraints, the people in the city are facing serious risk of higher concentrations of PM. It was also established that smaller city undergoing urbanization were also prone to the threats of air pollution.

The study has broader significance for small Indian cities having similar demographic considerations undergoing urbanization and economic development.

CONCLUSION

The study clearly established trend of predomination of PM in the urban air. All the values recorded for the PM are far greater than the standards of the CPCB, India and the WHO for both residential and commercial areas. Values of gaseous pollutants recorded are lower than the prescribed standards or slightly greater than the standards, but long time exposure of even such small quantity may lead to acute respiratory diseases. Such higher level of RsPM and SPM in the city is extremely dangerous and harmful for human health as well as plant world, which is a matter of concern. Study also provided key reference data as well as highlighted the poor air quality of a small city. This is like an alarm bell, since air pollution as a whole, has been categorized as carcinogenic to humans by the WHO.

The study strongly recommends for strict compliance of pollution emission norms in small cities without delay. More traffic congestions are expected due to increasing population and buying capacity of the people. Thus, introduction of a reliable public transport system, innovative and firm traffic management strategies and use of green fuels like CNG will be invariably required in small cities as well.

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